7.—The petrology and probable stratigraphic significance of Aboriginal artifacts from part of south-western Australia

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Manuscript received 17 June, 1975; accepted 29 July, 1975

Abstract

Aboriginal rock and mineral artifacts found in the southern Northampton Block, Perth Basin, Naturaliste Block, and areas around Albany and Esperance, consist of dolerite, actinolite-rich rock, granite, schist, quartz, quartzite, silcrete, siliceous and ferruginous shale and seven varieties of chert. The chert includes novaculite from the Proterozoic Coomberdale Chert, mottled chert probably from the Lower Triassic Kockatea Shale, two varieties of veined epidote-bearing chert from metamorphosed Precambrian strata, opaline and chalcedonic chert from the Middle-Late Eocene Plantagenet Group, similar chert from amygdales of the Neocomian Bunbury Basalt, and fossiliferous cryptocrystalline chert from an unidentified Middle-Late Eocene unit. Artifacts are particularly abundant in the Perth Basin. The fossiliferous cryptocrystalline chert has been found in firmly dated contexts only at Devils Lair, in strata with radiocarbon dates of 19 000 to 12 000 B.P. It is widely distributed in a strip along the western coast and probably came mainly from the west when sea level was significantly lower than at present. Some flakes of fossiliferous cryptocrystalline chert in the southern part of the Perth Basin may have come from Plantagenet Group rocks. Most other artifacts in the basin were carried west from the Precambrian shield, but some in the north are of local origin. Fulgurite fragments are found in many artifact assemblages, but evidence of their utilization is lacking. Feldspar cleavage flakes are also rather common at some sites.

Introduction

The Perth Basin and adjacent shield areas in Western Australia contain numerous surface and near-surface accumulations of flaked stone artifacts (primary flakes and cores, utilized flakes and cores, and specific tool types). This paper describes their petrology, and that of the associated, less abundant ground stone material (axes and grinding stones). Shield areas near the Perth Basin covered in this report include the Naturaliste Block, the south-western part of the Northampton Block, and part of the Precambrian terrain along the southern coast, which is commonly covered by Plantagenet Group rocks. (See Johnstone *et al.* 1973 for a geological review of the region.) Many of the artifact sites listed in this paper were discovered by the author, or jointly by Mrs. S. J. Hallam and the author. Material from a few other sites was made available by Mrs Hallam, and by the Western Australian Museum.

The lithological composition of artifact assemblages at the sites was estimated by counting 100 or more flakes. The abundance of artifacts in the Perth Basin is notable, and as those revealed (mainly in sand blow-outs) must represent a practically insignificant proportion of the total, the volume of transported rock material is truly remarkable.

The rock types used include dolerite, actinolite-rich rocks (rare as artifacts), granite, schist, quartzite, silcrete, siliceous and ferruginous shale, and at least seven varieties of chert, including novaculite, mottled chert, two varieties of veined epidote-bearing chert, two varieties of opaline and chalcedonic chert, and fossiliferous cryptocrystalline chert.

Most of the artifacts described come from blown-out areas of sandy country and commercial sandpits, and their relative stratigraphic positions and times of accumulation have been established only in a broad way. According to Hallam (1972) sites assumed to be early on typological grounds are almost exclusively scraper assemblages and are very high in fossiliferous chert (the fossiliferous cryptocrystalline chert of this paper). Late assemblages contain many fabricators and are high in quartz. Intermediate sites have a high backed-blade component and are lithologically rather heterogeneous. Hallam also noted that near-coastal sites around Perth are rich in fossiliferous chert. This investigation shows that sites with abundant fossiliferous cryptocrystalline chert are concentrated within a belt in the central and northern Perth Basin that extends up to 40 kilometres inland. Flakes are commonly found where the coastal white or grey sand (the Quindalup Dune System of McArthur & Bettenay 1960) has been blown away to reveal underlying yellow or yellow-brown sand (Spearwood Dune System) commonly with emergent limestone pipes and pillars. Farther inland they are concentrated in blown-out areas of other sand formations. In commercial sandpits, artifacts are normally concentrated in the walls about 2 m below the original dune surface.

Patterns of lithologic distribution are fairly clear (Tables 1 and 2). Fossiliferous cryptocrystalline chert is found in almost all near-coastal assemblages between Gregory and Black Point some 700 km to the south. Between Gregory and Eneabba (about 220 km) the proportion of this chert in the assemblages is less than 10 per cent and commonly closer to 1 per cent. From the Eneabba area to Mandurah (300 km), referred to hereafter as the Eneabba-Mandurah belt, fossiliferous cryptocrystalline chert is invariably present and is abundant (above 10 per cent, locally above 75 per cent). South of Mandurah toward Black Point (about 200 km) the chert apparently composes part of most near-coastal flake assemblages, but the number of

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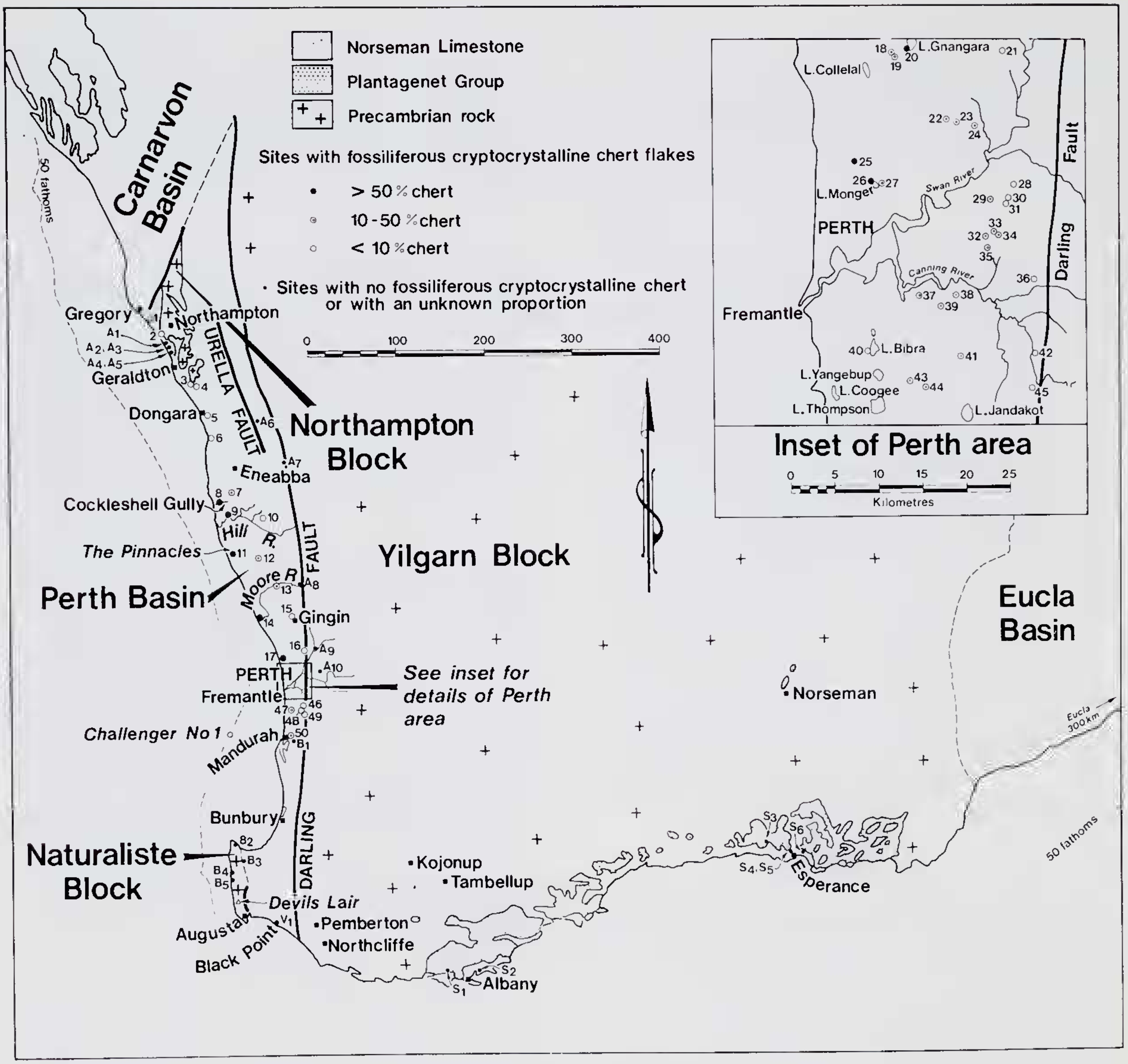

Figure 1.—Map of south-western Western Australia showing flake localities. See Tables 1 and 2 for details about localities. All scales in km.

flakes is normally small, and meaningful proportions cannot be given. Inland from the coast there is a general but uneven decline in fossiliferous cryptocrystalline chert: near the north-eastern margin of the Perth Basin it is absent, and near the central eastern margin it ranges from 0-5 per cent. There is insufficient information to generalize about the south-eastern margin. It should be noted that estimates are difficult at sites on the Precambrian shield, for quartzite flaked by Aborigines is hard to distinguish from chips formed by weathering of local rock.

Mottled chert, feldspar, and siliceous and ferruginous shale are restricted to the area north of Dongara, whereas opaline and chalcedonic chert is confined to sites near the south coast. Quartzite is the most widespread and abundant material. Silcrete and veined epidote-bearing chert are also fairly widespread but are normally minor constituents. Novaculite is uncommon south of the Perth metropolitan area.

Man has been in Australia at least 32,000 years (Barbetti & Allen 1972) and perhaps far longer. In Western Australia excavations at Devils Lair, near Augusta, include artifact-bearing strata dating from about 12 000 to about 25 000 BP, and the bottom of the deposit has not been reached. Quartz artifacts are found in strata representing the whole time interval, but fossiliferous cryptocrystalline chert has so far not been found in strata older than about 19 000 years (Dortch & Merrilees 1973; Glover 1974*a*).

This paper is based on the examination of some 18 000 chips and flakes in handspecimen,

Table 1

Sites at which the proportion of fossiliferous chert is known.
Sites are located on 1 : 250,000 Series R 502 maps, and co-ordinates are based on grid references estimated to the nearest hundredth. Co-ordinates refer to centre points of large sites.

No.	Type of site	Map co-ordinates	Flakes counted	% fossiliferous chert
1	Sand blow-out, Ridley's Pool area	22744932	448	4
2	Sand blow-out, 3 km E Horrocks Beach	23444785	877	1
3	Sand blow-out, 2 km S Walkaway	27164108	376	1
4	Sandy patch, Wondado Springs	28404048	325	0
5	Sand blow-out 0·8 km E Pell Bridge	29453744	301	0·5
6	Sand blow-out E side L. Arromore	29843469	400	1
7	Road cutting in sand, Kooringa area	32002760	319	45
8	Sandy soil, N bank Cockleshell Gully	30372666	215	75
9	Sand blow-out, N bank Hill River	31492481	310	63
10	Sand spoil from dam about 1 km W. Dinner Hill	35772452	154	2·5
11	Sand blow-outs, Pinnacles area	31692063	2107	69
12	Sand near dam, Caro Station	34651927	249	41
13	Road cutting in sand, S bank Moore River, Regans Ford	36921652	133	17
14	Blow-outs in yellow sand near mouth of Moore River	34851205	886	86
15	Sand blow-out 2 km NNW Gingin Railway Station	38801260	406	3
16	Sandy area 6 km S Bullsbrook East	40370758	290	3
17	Blow-outs in yellow sand 1 km north Mullaloo Beach	37190695	127	87
18	Gnangara Sandpit	38370671	249	20
19	Brambles Sandpit	38410669	193	13
20	Sandy area, SW margin of Lake Gnangara	38550680	684	54
21	Bell Bros. Sandpit, Gnangara Road	39730675	309	5
22	Ready Mix Sandpit, Beechboro	39040592	307	23
23	Road cut in sand, Beechboro Road	39180588	228	29
24	Widgee Road Sandpit, Beechboro	39380584	291	16
25	Sand Patch, S side Talbot Way, Woodlands	37880540	373	71
26	Sand dune, NW of Lake Monger	38120517	344	58
27	Red sand, E shore of Lake Monger	38220512	642	44
28	Sandpit, Maida Vale	39880510	347	16
29	Exposed sand, airport runway extension	39600492	348	17
30	Rail cutting in sand near Wittenoom Road, Maida Vale	39820496	353	3·5
31	Sand blow-out near Bingham Street, Maida Vale	39800490	384	7·5
32	Exposed sand, Kewdale	39550449	669	32
33	Sandpit, Hardey Road, Cloverdale	39630455	717	23
34	Exposed sand, Newburn Road, Kewdale	39690452	413	19
35	Sand blow-out N side Dowd Street, Kewdale	39550434	318	21
36	Sandpit NE White Street, Orange Grove	40140397	306	6
37	Exposed dune, corner High Road and Leach Highway, Riverton	38700377	378	20
38	Exposed sand, Metcalf Road, Lynwood	39160377	181	14
39	Sand blow-out near Riley Road, Nicol Road, Lynwood	38980364	317	19
40	Snashall Bros. Sandpit, Bibra Lake area	38080308	394	17
41	Coopers Sandpit, Canning Vale	39220303	277	16
42	Hot Mix Sandpit, Gosnells	40110265	361	6
43	Ready Mix Sandpit, Forrest Road, Jandakot	38590273	299	29
44	Calsil Sandpit, Forrest Road, Jandakot	38780266	118	13
45	MWSS & DB Sandpit, Lilian Avenue, Armadale	40110266	359	0·25
46	Fremwells Sandpit, Hopkinson Road, Cardup	39710126	1589	4
47	Wellard Sandpit, Parmelia	38540114	174	18·5
48	Sand blow-outs, Lang's Farm, Mundijong	39820092	500	2
49	Sand blow-out, 0·5 km S railway bridge, Mundijong	40040058	374	7·5
50	Sandpit 4·5 km E Stake Hill Bridge, Mandurah	38049805	116	28·5

and microscopic study of 180 thin sections. The study was supplemented by several complete and partial chemical analyses, by X-ray determination of some silica minerals, and by examination of some silcretes with the scanning electron microscope.

Colour designations used in the lithologic descriptions are taken from the Rock-color Chart distributed by the Geological Society of America (Rock-color Chart Committee 1963), and are accompanied by a numerical code from the same source.

Lithologies

Dolerite

Dolerite was used for grinding stones and axe-heads, and is not common as flaked artifacts. The best dolerite for flaking is fine-grained and comes from small dykes or from the chilled margins of large dykes on the Yilgarn Block. Waterworn boulders were a source of some dolerite.

Actinolite-rich rocks

Actinolitic rocks are rather rare as artifacts, and have so far only been found at Wondado Springs (site 4) and near Howatherra (Site A_2), where they compose less than 5 per cent of the flakes. The finer grained rocks are aphanitic, black (N 1) through greenish black (5G 2/1) to dusky yellow green (5GY 5/2) and are tough, with conchoidal fracture. They are made up mainly of interlocking actinolite grading to tremolite, with pyrite, magnetite, quartz, and other minerals. Coarser grained rocks tend to be greenish grey (5G6/1) with a less well developed conchoidal fracture, and are made up mainly of andesine and actinolite. They resemble uralitized dolerite.

Table 2

Sites at which the proportion of fossiliferous chert is not precisely known.

Some sites (A_1–A_{10}) may contain numerous fragments weathered from nearby rocks. Other sites (B_1–B_5, V_1) have yielded insufficient flakes, or have not been closely investigated. Museum sites have not been inspected by the author. Sites S_1–S_6 are near Plantagenet Group rocks and contain distinctive chert flakes. Map co-ordinates as for Table 1, except that sites B_2–B_5 are located on Sheet 1930 (Edition 1) Series R611.

Site No.	Type of site	Map co-ordinates	Fossiliferous cryptocrystalline chert*	Chert with colloform opal and/or abundant microcrystalline chalcedony*
A_1	Sand blow-out 1·4 km W Oakabella Homestead	24824666	r	a
A_2	Sand blow-out 1·5 km S Howatharra, 400 m S Royce Homestead	25234603	r	a
A_3	Sand blow-out, Howatharra area, 3 km WSW Royce Homestead	25054596	r	a
A_4	Small sand blow-outs in field, W side Highway No. 1, 0·8 km S Buller River	25214483	r	a
A_5	Small sand blowouts, 0·5 km W locality A_4	25144485	a	a
A_6	Sandplain 2 km S Yandanooka near Government Windmill, Bundanoon	35413660	a	a
A_7	Sand blowout about 3 km SW Winchester, 0·7 km NW Kilcur Pool, near mill	39003096	r	a
A_8	Sand blowout 4·5 km SSW Gillingarra, 0·5 km W highway	40331674	r	a
A_9	Junction of Avon and Brockman Rivers	41210814	a	a
A_{10}	S side Jane Brook, about 1·3 km E Stoneville	41870573	a	a
B_1	Sandpit about 7 km N Pinjarra, North Dandalup Road	38739728	p	a
B_2	Small sandpatch 0·4 km SSW Meelup Spring, S Dunsborough-Naturaliste Road	LH206816	p	a
B_3	Sandpit E Bussel Highway at junction with Yelverton Road	LH296653	p	a
B_4	Sand blowouts, Cowaramup Point	LH128509	r	a
B_5	Small sand blowouts, S side Margaret River Road 1 km NE Wildcliffe House	LH157395	p	a
S_1	Sand, N side Albany-Denmark Road 3 km W Torbay	56146730	a	p
S_2	Road cutting in sand, Nannarup Road 3 km NNW Nannarup	60386803	a	p
S_3	Sand on laterite, between Dalyup tennis courts and Dalyup River N side Esperance Albany Highway	46028345	a	p
S_4	Railway cutting in sand, 0·5 km N Shark Lake Siding	48778275	a	p
S_5	Sand blowout in dune, 0·25 km N Shark Lake Siding	48748274	a	p
S_6	Sand blowout, S side Esperance Road 3·5 km W Mt. Edward	50128247	a	p
B1038	Yeagerup Dune, 16 km S Pemberton		p	a
B271	Cleared paddock, Half Moon Farm, 8·4 km SW Kojonup		Mainly silcrete, no chert	
B1763	Sand dune, E shore large lake, E side main road, 4 km SSE Lake Banks Hst. near Tambellup		p	a
V_1	Sand blowout about 1 km E Black Point	35417488	Chert from volcanic amygdales present	

* a = absent, r = rare, p = present

Granite and Schist

Fragments of granite and schist are found in some Perth Basin sites, and the rocks would have been carried westerly from the Yilgarn Block. Most of the material examined, because of its coarse grain size and poor coherence, was probably unsuitable for flaking, and was used mainly for grinders.

Quartz

Quartz (rock crystal) was used where available, and large clear crystals were not spared. Many chips resemble flaked window or bottle glass, from which they can be distinguished by their anisotropism and lack of bubbles. Rock crystal, though not abundant, is widespread near shear zones on the Yilgarn Block and no specific sites of origin have been determined.

Quartzite

The term quartzite is used for all polycrystalline quartz rocks because it is difficult to distinguish fragments derived from such diverse parents as large quartz-rich pods (the quartz blows of prospectors), metaquartzites, and highly silicified orthoquartzites such as those found interbedded with chert in the Proterozoic Moora Group. It is not always easy, in fact, to distinguish quartzite and Coomberdale Chert without microscopic examination. Quartzite was widely utilized for grinding implements and flakes in south-western Australia, and is the main constituent at many sites in the Perth Basin. Source rock is abundant on the Yilgarn Block and on other Precambrian terrains, and the artifacts generally give no precise indication of their place of origin. Some have been broken from waterworn boulders, which would have saved the work of quarrying. In the northern part of the Perth Basin rounded pebbles and boulders from the Tumblagooda Sandstone and Mesozoic units seem to have served locally as sources.

Feldspar

A significant proportion (1-28 per cent) of flakes at some sites north of Dongara (sites 2, and A_1-A_5 inclusive) is made up of cleaved perthite. The flakes are commonly about 3 cm x 2 cm x 1 cm, but they vary in size between wide limits. The overall colour of many flakes is pale yellowish orange (10 YR 8/6) to greyish orange (10 YR 7/4) with the host microcline coloured in shades of brown, pink and grey, and the abundant plagioclase veins in shades of yellow.

Feldspar has two perfect cleavages (001) and (010), and reflection from these smooth surfaces causes the flakes to glisten in the sun. The cleavages meet at an angle of 86° to form straight edges which would be useless for cutting. It is not known if the feldspar was used by the Aborigines.

Fulgurites

Fragments of lechatelierite (silica glass) from sand fulgurites have been found at ten artifact sites in the Perth Basin, and have been described in detail elsewhere (Glover 1974b, 1975). Sand fulgurites are narrow tubular bodies up to two or three metres long that resemble plant roots in external shape and orientation, and they form from the fusion of sand by lightning. The tubes commonly break into fragments of a few square centimetres in area, and remain as lag in dune blow-outs. Fulgurites that formed in sand blown over former artifact sites can thus be concentrated with the artifacts during subsequent deflation. Some older fulgurite fragments may have been carried to the site by Aborigines, but evidence of handling would be almost impossible to establish.

In handspecimen, non-tubular fulgurite fragments can be recognized by a smooth, translucent somewhat mammilated appearance on one surface, and a rough opaque aspect, with numerous embedded sand grains, on the other. Microscopically the glass is vesicular with a refractive index close to 1.461.

Silcrete

Silcrete fragments can be recognized in handspecimen because they contain quartz grains, commonly in shades of light grey, in a uniform, porcellaneous cement that generally ranges between very pale orange (10 YR 8/2) and pale yellowish orange (10 YR 3/6). The rock has pronounced conchoidal fracture.

In thin section most of the silcrete fragments consist essentially of quartz grains in colourless or pale brown cement. A silcrete from the Northampton area (see Fig. 2B) has a more complex clastic assemblage and contains quartz (some grains with well-defined outgrowths), glauconite, microcline, leucoxene, tourmaline, and siliceous grains of unknown origin. The cement seems to be isotropic under the polarizing microscope, but X-ray powder photographs of a typical specimen (Uni. No. 74,628) from site 32 show quartz lines. The refractive index is close to 1.549 ± 0.002, and the specific gravity is indistinguishable from quartz in heavy liquids. Scanning electron microscopy shows that the average grain size is about 1 μm. It seems therefore that the mineral is quartz whose unusual optics are caused by its finely divided state.

Silcrete apparently forms in at least two ways (see Hutton *et al.* 1972) and can form from different kinds of rock. Silcretes from different sources are therefore likely to differ texturally and even mineralogically, in rather distinctive ways. Silcrete artifacts in the Perth metropolitan area, and at Gingin, resemble outcropping silcrete from the Kojonup area very strongly.

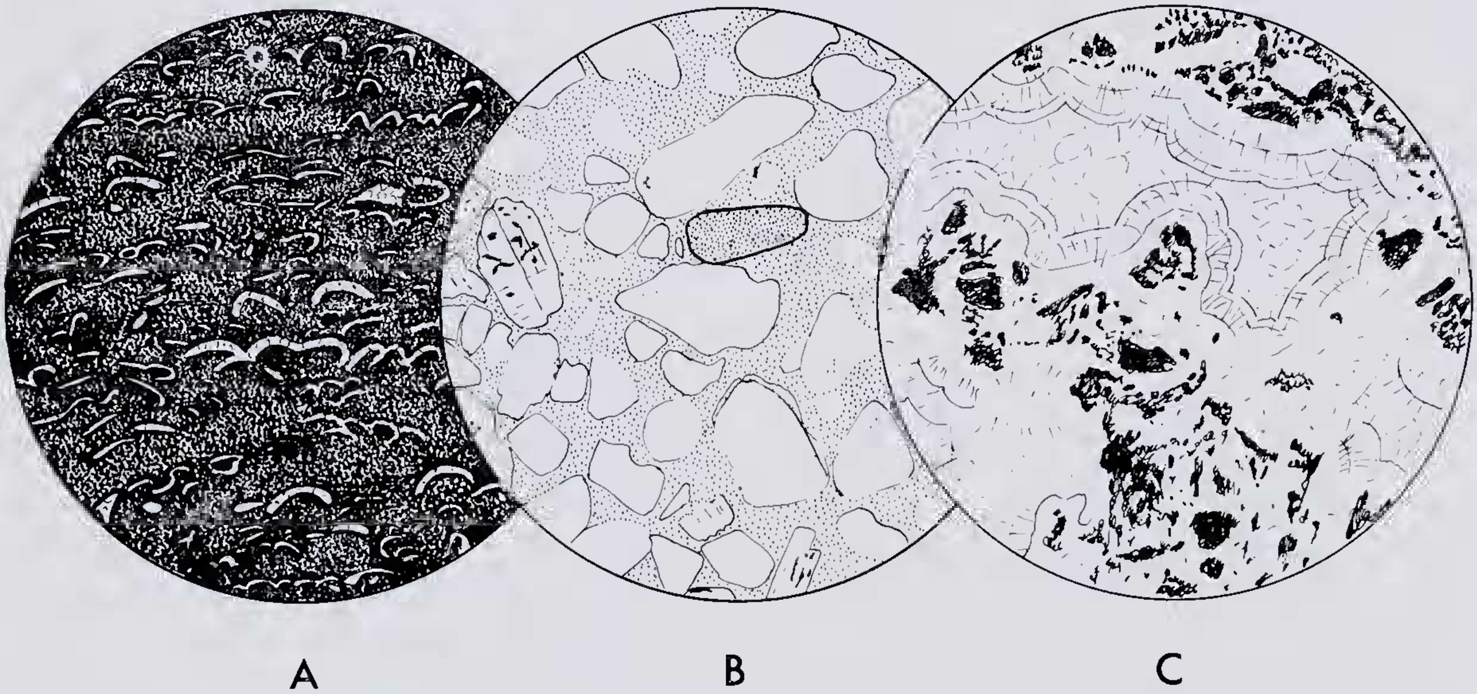

Figure 2.—Thin sections of flakes. A.—Siliceous ferruginous shale (Uni. No. 74451/1) from site 2, Horrocks Beach area The curved siliceous bodies of microcrystalline quartz may be algal. Cement consists of hematite and goethite. Flake probably derived from Kockatea Shale. Diameter of field 1.3 mm. B.—Silcrete (Uni. No. 74501) from site A_3, Howatharra area. Colourless grains without cleavage are quartz, colourless grains with cleavage are microcline. Dark grain with high relief is tourmaline. Cement is very finely divided quartz. Diameter of field 1.3 mm. C.—Mottled ferruginous chert (Uni. No. 74481) from site A_5, Buller River area. Dark areas contain mixture of hematite, limonite and cryptocrystalline silica. Colourless areas contain radiating chalcedony with cores of microcrystalline quartz. Probably derived from Kockatea Shale. Diameter of field 1.3 mm.

Siliceous ferruginous shale

The siliceous ferruginous shale flakes are tough, laminated, have conchoidal fracture and range in colour from greyish red (5R 4/2) to moderate brown (5 YR 4/4 to 5 YR 3/4). Microscopic examination reveals that up to 15% of some flakes is made up of bodies with strongly curved to fairly straight walls from 0.01 to 0.05 mm thick, composed of microcrystalline quartz, in a cement of hematite and goethite (see Fig. 2A). This rock is found at sites 2 and A_2 and is apparently restricted to the northern part of the Perth Basin. It is the same as that illustrated by Karajas (1969, fig. 24, unpubl. data) from the so-called algal unit of the Triassic Kockatea Shale.

Chert

Classification

According to the hypotheses of primary origin, chert is deposited as silica gel, or forms by partial redistribution, *in situ*, of silica precipitated by organisms such as diatoms and radiolarians. Secondary origin can be demonstrated for many cherts by their field relationships or palimpsest microstructures, and generally involves replacement of calcareous rocks.

Though there is a considerable literature, advances in chert petrology have been slow (see Dapples 1967) and classification and nomenclature have not kept pace with other sedimentary rock groups, notably the carbonates. A descriptive nomenclature partly based on that of Williams, Turner and Gilbert (1954) is adopted to distinguish between the varieties of chert artifact described here. The common term *flint* used by some as a synonym for chert, and by Williams *et al.* and others for a tough grey or black variety of chert with conchoidal fracture, is unsatisfactorily defined, and is not used. The term *chert* is taken to include compact siliceous rocks composed of opal, chalcedony and cryptocrystalline or microcrystalline quartz, or a mixture of these constituents. Chert can be any colour, and can originate in several ways.

Chert composed mainly of microcrystalline quartz is called novaculite in this paper, a term used in parts of the United States and already applied to the Coomberdale Chert by Logan and Chase (1961). Apart from novaculite the descriptive terms opaline and chalcedonic chert, mottled ferruginous chert, veined epidote-bearing chert, and fossiliferous cryptocrystalline chert, have been used for distinctive local varieties. There is unfortunately disagreement about the size limits indicated by the commonly used terms "cryptocrystalline" and "microcrystalline" (see Bissell and Chilingar 1967, Table IV). This paper follows Pettijohn (1957, Table 18) in taking the boundary between the two at 0.01 mm, as it then forms a suitable dividing line between two distinctive varieties of chert found in Western Australia. Crystal size in cryptocrystalline chert is taken to be less than 0.01 mm, whereas microcrystalline grains are defined as being greater than 0.01 mm, but too fine for observation with the naked eye.

Novaculite

Novaculite artifacts are commonly translucent in thin chips, and range through shades of light to dark grey, greyish yellow, pink, and red. They are hard, dense and non-porous. Most are banded, but some are intraformational breccias. Artifacts without such structures are difficult to distinguish from quartzite without microscopy.

Twelve novaculite artifacts were sectioned and consist essentially of microcrystalline quartz, locally cut by quartz veins up to 0.5 mm thick. The interlocking quartz crystals range in diameter mainly between 0.05-0.25 mm, and two of the flakes (Nos. 74527/3, 74536/2) show palimpsests of dolomite rhombs clearly outlined by iron oxide (see Fig. 2B).

The novaculites show macroscopic and microscopic features characteristic of the Coomberdale Chert from which they were certainly derived. Novaculite artifacts are far less frequent than artifacts of fossiliferous cryptocrystalline chert at central Perth Basin sites, despite the abundance of strongly outcropping novaculite along many parts of the eastern margin of the basin. Presumably the almost perfect conchoidal fracture of the fossiliferous cryptocrystalline chert made it the more useful of the two.

Opaline and chalcedonic chert

The opaline and chalcedonic chert artifacts superficially resemble the fossiliferous cryptocrystalline chert artifacts described below, but they have a less developed conchoidal fracture and may be particoloured or mottled. The chalcedony commonly ranges from shades of light and medium grey (N8—N5) to pale yellowish brown (10 YR 6/2) and the opal ranges from white (N9) through very pale orange (10 YR 8/2) to more brownish colours where strongly stained. The minerals can be easily distinguished in some artifacts because the chalcedony is translucent whereas the opal is not.

Under the microscope (Fig. 3C) the chalcedony is generally microcrystalline, clear, and colourless whereas the opal, which has pronounced negative relief, is somewhat cracked and ranges through pale and very pale shades of brown and orange. The opal is colloform in places and commonly includes bodies of radiating-fibrous chalcedony, with quartz cores showing undulose extinction. Some of the opal is completely isotropic, but most of it has very low birefringence and fibrous structure under crossed polarisers. X-ray powder photographs of slightly birefringent opal from Esperance show several broadened α-cristobalite lines characteristic of "common" opal, i.e. the opal-CT of Jones & Segnit (1971), which is the same as Mallard's lussatite (Mallard 1890).

Palimpsests of shell fragments, and unsilicified glauconite pellets are found in some opal but are less common in the chalcedony.

Flakes of opaline and chalcedonic chert are abundant at sites in the Denmark, Albany and Esperance areas, and are mineralogically and texturally identical with nearby siliceous Plantagenet rocks. There is no doubt about the local derivation of these artifacts.

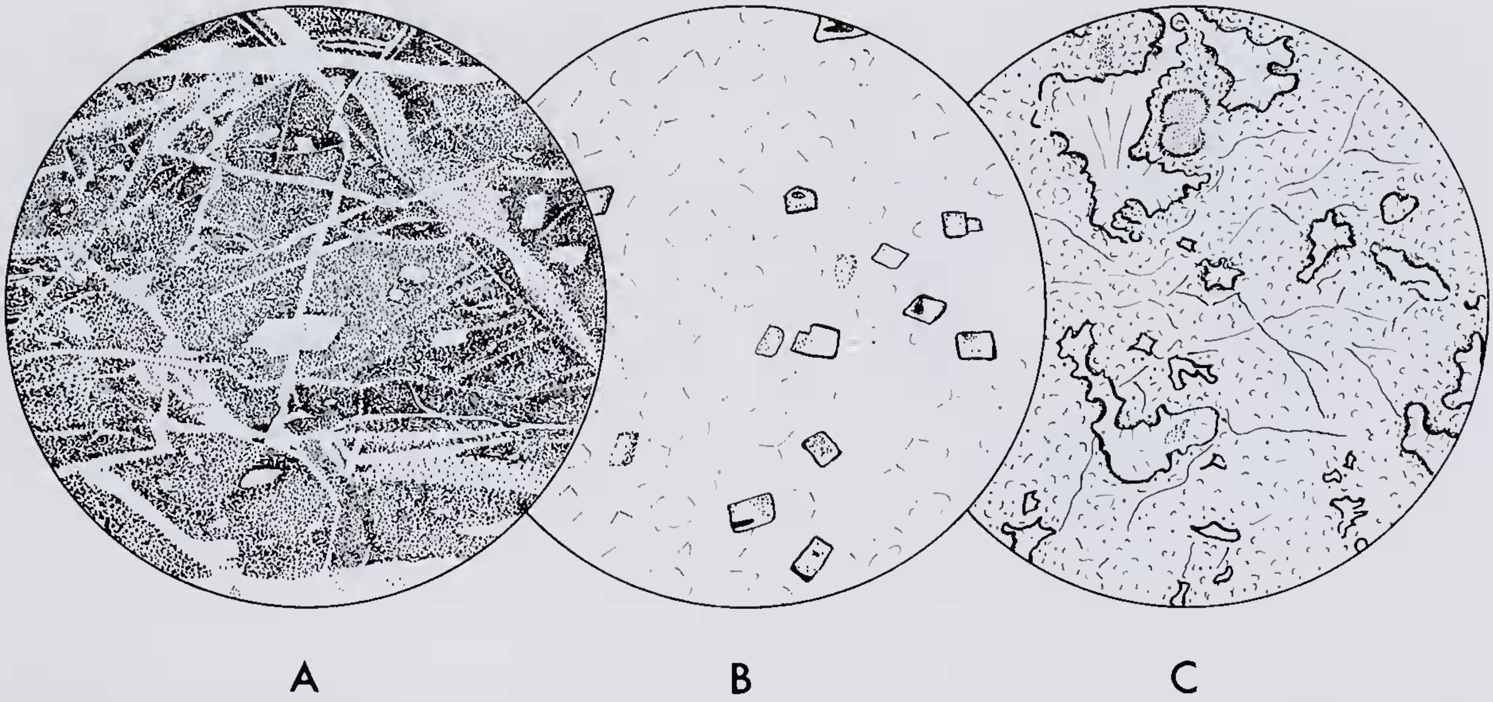

Figure 3.—Thin sections of flakes. A.—Veined epidote-bearing chert (Uni. No. 74671) from site 15, Gingin area. Veins of microcrystalline quartz cut cloudy groundmass of microcrystalline and cryptocrystalline epidote and silica. The large colourless grains consist of aggregates of interlocking microcrystalline quartz. The rock resembles in texture a meta-volcanic rock or a metamorphosed tuff, and is probably derived from Precambrian terrain. Diameter of field 3.5 mm. B.—Novaculite (Uni. No. 74536/3) from site A_7, Winchester area. Note the siliceous, rhomb-shaped palimpsests of dolomite, outlines by iron oxide, in cement of microcrystalline quartz. Probably derived from Coomberdale Chert. Diameter of field 0.26 mm. C.—Opaline and chalcedonic chert (Uni. No. 74674) from site S_6, Esperance area. The opal (stippled, with cracks) contains bodies of radiating-fibrous chalcedony. An indistinct organic remnant can be seen in the opal toward the top of the field. Derived from Plantagenet Group. Diameter of field 1.3 mm.

Farther west, in the Black Point area, siliceous amygdales weathered out of the Neocomian Bunbury Basalt are found in artifact assemblages. The mineralogy of the amygdales is complex and variable, but many contain only colloform common opal (opal-CT), chalcedony and quartz, and chips from these amygdales are practically indistinguishable from palaeontologically barren chips of the Plantagenet chert. Flakes containing zeolites, celadonite or barite can be confidently ascribed volcanic origin.

Mottled ferruginous chert

Mottled ferruginous chert flakes range in colour from shades of yellowish brown to purple and are mottled with spots or patches in shades of orange and grey. Microscopic examination (Fig. 2C) shows that the mottling is caused by irregularly shaped masses of intimately associated limonite, hematite and cryptocrystalline silica separated by fringes of radiating chalcedony from aggregates and microcrystalline quartz.

Flakes of the rock are fairly numerous at site A_4 (10%) but are not normally common and seem to be confined to the northern part of the Perth Basin. Their origin is uncertain, but they may be derived from silicified portions of the Triassic Kockatea Shale.

Veined epidote-bearing chert

Veined epidote-bearing chert flakes are brown, grey and yellow, with an olive or green cast from disseminated epidote, and are cut by narrow (generally <0.5 mm) quartz veins.

Two varieties have been distinguished microscopically. One variety contains large, composite grains (up to 0.7 mm in diameter) consisting of interlocking microcrystalline quartz, and rarer large epidote grains in a cloudy groundmass of cryptocrystalline to microcrystalline silica and epidote. Some of the large composite quartz grains have remarkably straight edges, and resemble silicified phenocrysts in a metamorphosed volcanic rock or crystal fragments in a metamorphosed tuff. The rocks are microfaulted and are cut by narrow veins of microcrystalline quartz (see Fig. 3A). The second variety consists of poorly sorted, angular, strained quartz grains, microcrystalline quartz aggregates, and microcline and epidote grains in a cryptocrystalline to microcrystalline matrix of silica and epidote. These rocks are also veined and microfaulted, and resemble metamorphosed greywackes (see Fig 4A). The origin of both rock types, however, is still rather speculative[1].

Veined epidote-bearing artifacts are widely distributed throughout the Perth Basin and on its margins, but constitute only a very small proportion of material at sites examined. The parent rock almost certainly comes from shield areas.

Fossiliferous cryptocrystalline chert

Petrology: The surface colour of the fossiliferous cryptocrystalline chert flakes is generally

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[1] These textures may be misleading. The flakes also resemble mylonitized Precambrian rock examined after this paper went to press.

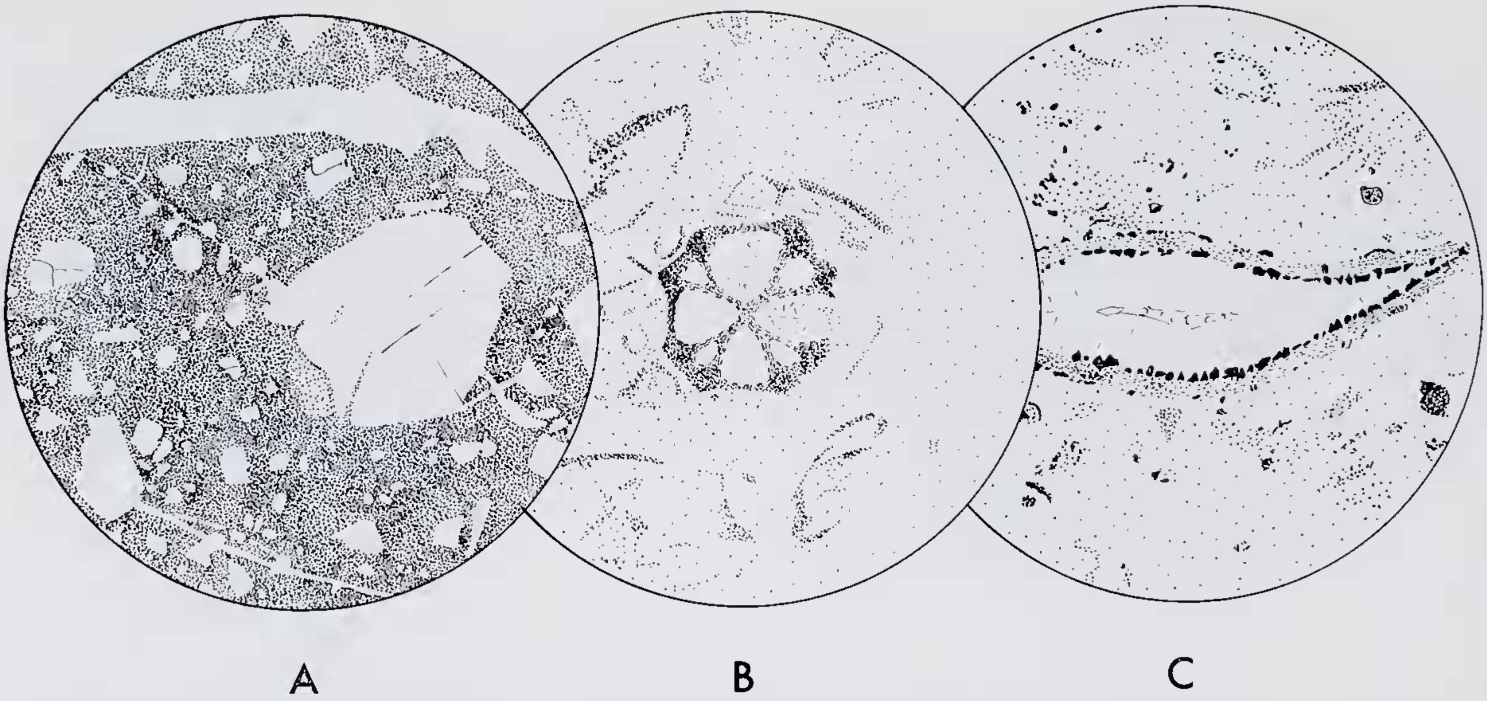

Figure 4.—Thin sections of flakes. A.—Veined epidote-bearing chert (Uni. No. 74699) from site 49, near Mundijong. Veins of microcrystalline quartz cut a cloudy matrix of microcrystalline and cryptocrystalline epidote and silica. Large grain with cleavage is microcline, other grains consist of strained quartz, or aggregates of quartz. The rock is probably derived from Precambrian terrain, and resembles meta-greywacke. Diameter of field 1.3 mm. B.—Fossiliferous cryptocrystalline chert (Uni No. 74606/1) from site 11, the Pinnacles area. Palimpsests of bryozoan and other fossils in matrix of cryptocrystalline silica. Probably silicified Eocene limestone from off-shore source. Diameter of field 1.3 mm. C.—Fossiliferous cryptocrystalline chert (Uni. No. 74606/2) from site 11, the Pinnacles area. Palimpsest of small bivalve in cryptocrystalline silica. Note drusy, opaline fringe. Probably silicified Eocene limestone from off-shore source. Diameter of field 1.3 mm.

close to the colour of the surrounding sand, and ranges mainly from white through pale shades of grey, yellow, brown and orange. Common surface colours are white (N9), pinkish grey (5 YR 8/1), greyish yellow (5 Y 8/4), pale yellowish brown (10 YR 6/2), light brown (5YR 5/6), very pale orange (10 YR 8/2) and greyish orange (10 YR 7/4). Sections through some flakes show that the outer colour is a patina that gives way to white or pinkish grey (5 YR 8/1) for up to two or three mm, and passes into a core of pale yellowish brown (10 YR 6/2) or a similar colour. Other flakes, however, particularly those taken from white sand, are white or nearly so throughout.

Thin-section examination reveals partly to completely silicified Bryozoa, Foraminifera, sponge remains, small bivalves and echinoderm fragments together with a few unsilicified glauconite pellets in an essentially cryptocrystalline matrix (Figs. 4B, 4C). A little quartz sand and silt is present in some of the chips. The epithet cryptocrystalline is justified because over 50% of the rock is composed of grains less than 0.01 mm in diameter, but it is not uncommon for about 30% of the matrix to consist of chalcedony grains between 0.01 and 0.04 mm in diameter, with somewhat coarser chalcedony filling fossil tests.

Many fossils are partly replaced by very finely divided opal, or have a drusy opaline fringe about 0.005 mm thick. In places the fringe is directed outward from the shell surface. The small size and high negative relief of the opaline bodies make them practically opaque under magnifications of less than X100, and where finely divided opal is abundant it resembles cloudy argillaceous material. A few larger opaline bodies attain a length of 0.02 mm, and have pitted surfaces as though etched. A well-developed opaline drusy fringe is shown in Figure 4C.

Table 3.

Analysis of core and rim of a flake from the Pinnacles area.

*(from University specimen No. 74606)**

	Core	Rim
S_iO_2	97.9	98.2
TiO_2	0.01	0.01
$A1_20_3$	0.13	0.19
Fe_20_3	0.17	0.17
MnO	<0.01	<0.01
MgO	0.03	0.05
CaO	0.11	0.09
K_2O	0.04	0.04
Na_2O	0.01	0.01
P_2O_5	0.20	0.13
Loss on ignition	1.6	1.2
	100.2	100.1

* Analyst Supervise-Sheen Laboratories Pty. Ltd. XRF except P_2O_5 by colorimetry, SiO_2 by difference.

Most of the chert is evidently silicified fossiliferous limestone, and the texture suggests that it was originally biomicrite, according to the classification of Folk (1962). Remnants of cores commonly retain an uneven, roughly curved surface from which silicified Bryozoa project up to a millimetre or more. It appears from the general curvature and from the size of the larger cores, that the flakes were generally struck from chert nodules about the size of a man's fist. A few artifacts contain abundant spicules, indicating a spongolite precursor. A typical flake from the Pinnacles was analysed (Table 3) and shows almost complete silicification. The pale yellowish brown (10 YR 6/2) core and the white (N9) rim with its surface patina of very pale yellowish orange (10 YR 8/4) are not significantly different in composition.

The fossiliferous cryptocrystalline chert breaks fairly easily with smooth conchoidal fracture into sharp-edged flakes, which doubtless accounts for its widespread use. However, some chert fragments from sites of white sand have slightly rough surfaces, rather soft blunt edges, and are porous or even friable, apparently because of the removal of calcium carbonate, which can form up to 25% of incompletely silicified artifacts. Many flakes in white sand have probably disintegrated completely in this way.

An Eocene age is shown for the chert by the Bryozoa, and is confirmed by the presence in two chips of the Middle-Late Eocene foraminifer *Maslinella chapmani* Glaessner and Wade (Glover & Cockbain 1971).

Distribution and Source: Fossiliferous cryptocrystalline chert artifacts are found throughout the Perth Basin, and on the Northampton Block to the north and the Naturaliste Block to the south-west, a north-south distance of about 700 km. They are also found on the southern part of the Precambrian shield at a site near Tambellup. It has already been pointed out that the sites with the highest proportion of these chert artifacts are invariably near the western coast. Chert artifacts are known from sites frequented up to the ethnographic present (e.g. Lake Monger, see Fig. 1) and from strata about 12 000 to about 19 000 years old (Devils Lair, see Dortch & Merrilees 1973).

The "Middle-Late" Eocene dating of the fossiliferous cryptocrystalline chert is clearly crucial for no rocks of that age are known to outcrop in the Perth Basin (see for example Quilty 1974 *a*, *b*). There are several known units of requisite age elsewhere, namely Giralia Calcarenite, Merlinleigh Sandstone and Pindilya Formation in the Carnarvon Basin, Norseman Limestone on the southern Yilgarn Block, Plantagenet Group in the Albany-Esperance area, and Toolinna Limestone and Wilson Bluff Limestone in the Eucla Basin (see the correlation chart of Playford & Cope 1971).

The concentration of chert-rich sites near the western coast should be considered in the light of eustatic variation in sea level, as was well appreciated by Hallam (1974, p. 80). Recent data indicate that when the oldest known Western Australian chert flakes were being manufactured (about 19 000 years BP), world sea levels were 85-90 m (i.e. about 50 fathoms) lower than now (Mörner 1971). These data may be conservative, if applied to Western Australia coasts, according to new interpretations of global isostacy (see Chappell 1974). They imply that 19 000 years ago the coast would have been about 40 km west of Perth and about 90 km west of Geraldton and Bunbury, and the Perth Basin would have had roughly twice its present exposed area. Many artifact sites were probably covered by advancing seas during deglaciation, and there are probably numerous chert-rich sites off-shore. It is reasonable to hypothesize a westerly offshore source for the chert artifacts in silicified Late Eocene limestone. North-trending wedges of such limestone could well overlie the Late Palaeocene-Early Eocene Kings Park Formation, having survived later bevelling. Rock in these wedges could be exposed locally on the sea-floor, perhaps as windows through Pleistocene limestone. Reasons for these suppositions are set out in the three numbered paragraphs below.

(1) The ratio of chert to other rock types at artifact sites tends to increase markedly from east to west.

(2) It is unlikely that the remarkably large volume of chert at sites in the Eneabba-Mandurah belt would have been carried up to 500 or 600 km from the Carnarvon Basin or Albany-Esperance area. It is more likely to have come from western sources distant a few kilometres, or some tens of kilometres at most.

(3) Late Eocene rocks have been found in WAPET's Challenger No. 1 offshore well, about 60 kilometres west of Mandurah, between depths of 510 m and 590 m. These are the only known Late Eocene rocks in the Perth Basin, and have not been recorded from other off-shore wells. No wells have tested the rocks within 20 kilometres of the western coast opposite the Eneabba-Mandurah belt, where Late Eocene rocks, updip from the intersection in Challenger No. 1, could crop out on the sea floor.

Possible landward sources for the fossiliferous cryptocrystalline chert artifacts will now be considered. Of the Carnarvon Basin formations, Merlinleigh Sandstone and Pindilya Formation are lithologically unsuitable. The Giralia Calcarenite is fossiliferous, glauconitic and locally silicified but contains large Foraminifera absent from the fossliferous chert artifacts. The low concentration of chert flakes at near-coastal sites north of Eneabba, and the increased abundance of chert to the south, farther from the Carnarvon Basin, seem at first sight to support the idea that the Giralia Calcarenite was not the source of the chert. It is not unlikely, however, that some intermediate sites rich in chert are hidden off shore. The soundest reasons for doubting that the Giralia Calcarenite is the source of the abundant chert in the central Perth Basin are the absence of large Foraminifera in chert specimens examined, and the physical difficulty of transporting large volumes of chert over distances of up to 600 km [1].

The nearest possible sources of fossiliferous cryptocrystalline chert known in southern Western Australia are at least 500 km from the chert-rich artifact sites of the Eneabba-Mandurah belt. Units that should be considered are the Plantagenet Group and Norseman Limestone which patchily cover Precambrian basement rocks, the Toolinna Limestone farther east, and the Wilson Bluff Limestone exposed at Wilson Bluff near Eucla and in caves nearby. Chert artifacts from Wilson Bluff have been recorded near Eucla, and their use apparently continued into the ethnographic present. Geologically similar material has been quarried at Koonalda Cave, one hundred kilometres east of Eucla, which is shown to have been in use between 20 000 and 13 000 years ago (Polach *et al.* 1968). Chert from the Wilson Bluff Limestone closely resembles chert used for artifacts in the Eneabba-Mandurah belt, but is quite unlikely to have been carried 1 200 km to the area.

Chert flakes at sites around Esperance, Albany and Denmark are mainly composed of colloform opal and microcrystalline chalcedony, or of chalcedony alone, and are derived from local Plantagenet outcrops. No chert with colloform opal has been found in the Eneabba-Mandurah belt. Some Plantagenet chert from outcrop in the Northcliffe area kindly given to the writer by Mr. C. E. Dortch of the Western Australian Museum is composed of microcrystalline chalcedony. This resembles the Eneabba-Mandurah material more closely, but is generally coarser grained, and contains fewer microfossils.

Two cryptocrystalline chert flakes from the Tambellup area borrowed from the Museum (Museum No. B1763) have blurred textures under the microscope, but are fossiliferous and look rather like the Eneabba-Mandurah material. Two flakes from the Pemberton area (Museum No. B1038) are largely cryptocrystalline, but their unusual palimpsest texture, possibly derived from pelletal limestone, has not been precisely matched in the Eneabba-Mandurah material. The flakes from these two sites are of uncertain origin, but their most likely provenance is within a nearby area of Plantagenet rocks that are non-opaline and cryptocrystalline. It therefore seems that some Plantagenet rocks not yet examined resemble the Perth Basin flakes in lithology: if so, they could account for some of the chert flakes in the south of the basin. It is uncertain how far north such chert may have been carried, but material from the Plantagenet Group can hardly account for the distribution or volume of chert in the central part of the basin. It should be added that silicified Norseman rocks seem commonly to be fairly opaline, and therefore appear unsuitable as a source. Silicified Toolinna Limestone, farther east, has not been examined.

The source of the chert in the Perth Basin therefore remains rather enigmatic, but on balance the abundance and distribution of artifacts in the Eneabba-Mandurah belt favours the hypothesis of offshore origin for them. It also accords with Hallam's suggestion based on typology, that chert-rich sites in the Perth area were the earliest (Hallam 1972). After submergence of their source rocks the Aborigines would have been forced to use material mainly from the east, though some chert from old sites would have been re-used. The present position of sea level was probably attained by about 6 000 BP (Thom & Chappell 1975), and fresh chert would therefore have been unavailable by that time.

Conclusions

The full ethnographic significance of the artifacts will have to await further typological, stratigraphic and petrologic studies. The search for Middle-Late Eocene rocks in future off-shore wells or in dredged material is especially important. At present, the data demonstrate local derivation of material near the Northampton Block and in the Albany-Esperance area, and east-west transportation of Precambrian rocks throughout most of the Perth Basin. Superimposed on this model is a probable pattern of west-east transportation in the Eneabba-Mandurah area, of fossiliferous cryptocrystalline chert from sites now submerged. In the southern part of the Perth Basin there may be chert from both the west and Plantagenet rocks in the east. The conclusions are set out individually below.

(1) The flakes of mottled chert, and siliceous and ferruginous shale at northern sites were locally derived.

(2) The fossiliferous opaline and chalcedonic chert on the south coast was derived locally from the Plantagenet Group. Some of the non-fossiliferous material came from amygdales in the nearby Bunbury Basalt.

(3) The quartz, quartzite, dolerite, granite, schist, novaculite and veined epidote-bearing chert in the central Perth Basin came from east of the Darling Scarp. Each rock probably came from a number of localities. River boulders were a significant source of quartzite and dolerite.

(4) The fossiliferous cryptocrystalline chert found in the Eneabba-Mandurah belt probably came from an off-shore source in the west. Chert in the southern Perth Basin may have come partly from Plantagenet rocks to the east.

(5) The presence of fossiliferous cryptocrystalline chert in strata aged from about 12 000 years BP to about 19 000 years BP in the Devils Lair, and the remarkable abundance of similar material at some central Perth Basin sites, indicates extensive and persistent exploitation of the source rocks.

(6) Further petrological work on silcrete artifacts may throw additional light on the patterns of transportation.

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[1] Note added in proof. Dr. P. E. Playford, Geological Survey of Western Australia, reports (pers. comm.) finding bryozoal chert artifacts (including one large core 7 x 9 x 5 cm) on Tamala Station, about 20 km south of Shark Bay. These resemble the fossiliferou cryptocrystalline chert in handspecimen. Their significance is yet to be evaluated.

(7) Fulgurite fragments are concentrated with artifacts in blowouts by deflation. There is no evidence that fulgurites were worked by the Aborigines.

Acknowledgements.—Mrs. S. J. Hallam, Department of Anthropology, University of Western Australia, constructively criticized an early draft of this paper, and supplied some material for examination. The Museum of Western Australia also supplied material for examination. West Australian Petroleum Pty. Ltd. kindly released information about Late Eocene rocks encountered in their Challanger No. 1 well.

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